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Challenges to implementing greenhouse gas mitigation measures in livestock agriculture: A conceptual framework for policymakers

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ABSTRACT

Livestock agriculture is a significant global emitter of greenhouse gases (GHG) and the sector is under pressure to reduce its environmental footprint. Dairy, sheep and beef production are major contributors to emissions. Here, a study of the barriers to implementing GHG mitigation measures on sheep, beef and dairy farms in Wales provides insights into challenges for these sectors globally. Data were gathered from 18 stakeholder organisations and farmers using semi-structured interviews and facilitated workshops. Participants were asked about the challenges to implementing measures associated with different parts of the farming system. Data were analysed using a grounded theory approach. Identified themes covered the range of challenges to the implementation of climate-friendly agricultural practice described in a global review. A conceptual model linking categories of challenge (Practical limitations, Knowledge limitations, Cognitive limitations and Interests) was developed from the data. Comparing the findings with existing work on behavioural change revealed two major differences: i) The concept of Cognitive limitations highlighted the importance of cognitive processes recognised in social psychology to the implementation of change in livestock agriculture. It differentiated specific cognitive biases incorporated in behavioural models from constraints affecting the thought processes in which these biases develop and which they affect, ii) Critical elements such as power relationships and conflicting stakeholder interests were highlighted as important factors outside the scope of behavioural change models. The conceptual model developed can support policymakers in understanding and tackling challenges to change in livestock agricultural systems.

1. Introduction

Globally, agriculture has been estimated to contribute between 19 and 29% of total greenhouse gas (GHG) emissions (Vermeulen et al., 2012), and emissions from livestock systems, including the impacts of land use change for grazing and fodder production, have long been recognised as a particular challenge (Ripple et al., 2013; Steinfeld et al., 2006). In response, reports on climate change mitigation have emphasized the importance of reducing emissions from the agricultural sector alongside the development of a more sustainable food system that can deliver food security (Beddington et al., 2012). Much work has focussed on how best to implement climate change mitigation policies, with the scope of this literature recently reviewed at global level by the Organisation for Economic Cooperation and Development (Wreford et al., 2017). Several quantitative studies have investigated the costs of mitigation measures for agriculture (Jones et al., 2015), have studied farmers' ranking of specific mitigation measures using best-worst scaling (Dumbrell et al., 2016; Glenk et al., 2014; Jones et al., 2013), or have used carbon footprinting to measure and compare GHG emissions across farms in order to identify opportunities for mitigation (Hyland et al., 2016a). Quantitative tools have been developed to support stakeholders in identifying effective mitigation measures for reducing emissions in different agricultural systems (Feliciano et al., 2017).

A range of qualitative studies have also addressed decision-making in agriculture. Behavioural change theories provide conceptual models of behaviour and influencing factors, which can be applied in the land management sector (Morris et al., 2012). Attempts have been made to bring together approaches across disciplines to produce integrated behavioural models that support stakeholders working on climate change mitigation and adaptation (Darnton and Evans, 2013). Other work has examined farmers' perceptions of climate change (Hyland et al., 2016b) and the priorities and behaviour of farmers have been studied in relation to issues such as levels of engagement in agri-environment schemes (Wynne-Jones, 2013) and attitudes to entrepreneurship and the

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adoption of new technology (Morris et al., 2017). Actor-centred approaches such as these have produced typologies of farmers, enabling segmentation and policy targeted at specific farming groups, moving beyond homogeneous and simplified approaches that treat farmers as profit-maximisers (Jansen, 2009; Morris et al., 2017; Wynne-Jones, 2013). More recent problem-centred approaches focus on the barriers to implementing mitigation measures (Burbi et al., 2016; Feliciano et al., 2014). These studies highlight the fact that diversity in the values, beliefs and attitudes of farmers is matched by diversity of barriers to change between different regions, requiring context-specific investigation (Feliciano et al., 2014).

The agricultural sector in Wales provides a useful case study for investigating challenges to the implementation of GHG mitigation measures: i) it is dominated by three sectors (sheep, beef and dairy production) of global importance, ii) it faces a range of wider social, economic and environmental challenges. Agriculture in Wales is shaped by the country's topography (large upland areas) and climate (high annual rainfall with cool summers), which have favoured pasture-based production dominated by sheep and beef systems, alongside a smaller but growing dairy sector in more lowland areas (Morris et al., 2017; Wynne-Jones, 2013). Eighty percent of Welsh agricultural land is classified as Less Favoured Areas under European regulations (WG, 2013) with an ageing population of farmers and a high proportion of farm businesses providing low levels of income (Morris et al., 2017). Although climate change has been part of the policy agenda for Welsh livestock agriculture for a number of years, reductions in emissions from the sector only fell by 15% between 1990 and 2015 (Jones et al., 2017) with agriculture contributing 13% of national GHG emissions figures for Wales in 2015 (Jones et al., 2017). The Welsh Government has focussed on GHG emissions reduction and long term sustainability through the Environment (Wales) Act (WG, 2016) and the Well-being of Future Generations (Wales) Act (WG, 2015), recognising that the gradual rate of change in emissions to date reflects the need for improved implementation of reduction measures. The Climate Smart Agriculture Wales (CSA Wales) project (within which the current study was undertaken) was set up to support Welsh Government in achieving this improvement, taking into account the need to combine GHG mitigation with increased systemic resilience, sustainability and food security (Lipper et al., 2014). Assessing challenges to the implementation of GHG mitigation measures is an important pre-requisite to the design of effective policy (Feliciano et al., 2014). To provide such an assessment, the current study used a qualitative approach to explore and categorise the challenges facing effective GHG mitigation in the Welsh dairy, beef and sheep sectors based on the knowledge and perspectives of relevant stakeholders. Analysis of these challenges aimed both to inform local policy approaches, and to develop a conceptual model to support the effective implementation of GHG emissions mitigation measures in similar livestock systems in other countries.

2. Methods

In order to collect the views of stakeholders on the challenges to the implementation of mitigation measures in Welsh livestock agriculture, and potential solutions to these challenges, two approaches were used. Firstly, eighteen semi-structured interviews were carried out with representatives of stakeholder organisations (Table 1), using pre-prepared general questions to facilitate discussion (Patton, 1990) (Supplementary Material A). Relevant stakeholders either affecting or affected by the implementation of on-farm mitigation measures (Freeman, 1984) were identified through a mapping process involving CSA Wales project research partners and the Agriculture Industry Climate Change Forum (AICCF) – a key Welsh research-policy-stakeholder group focussed on the relationships between agriculture and climate change. The AICCF provided a core group of industry and governmental stakeholders, acting as a starting-point from which a snowball sampling approach was used to identify further individuals for interview and for workshop involvement among the mapped stakeholder groups, following the methods of Feliciano et al. (2014). The aim in engaging a range of stakeholder groups (rather than just farmers themselves) was to identify challenges to the implementation of mitigation measures at all levels, recognising that farmers interact with other stakeholders and make choices in the context of social, economic and environmental factors influenced by actors beyond the farm. A number of stakeholder groups were successfully engaged (Table 1). Interviews lasted around one hour; the number and length of interviews was consistent with other recent studies of the agricultural sector (Morris et al., 2017).

Table 1
Stakeholder groups and number of representatives involved in interviews and workshops.

Stakeholder group	Interviews	Workshops
Agricultural industry bodies	5	4
Farm consultants / trainers	1	4
Farmers	1	5
Farming unions	2	4
Policymakers	2	4
Researchers	3	1
Rural interest groups	4	0

Following the interviews, two workshops, focussing on dairy and on sheep and beef systems respectively, were held at Aberystwyth University during October 2017. Representatives of mapped stakeholder groups, along with individual farmers identified through AICCF members, were invited to attend. A total of 22 stakeholders from 13 organisations participated in the two sessions (Table 1). Activities were organised based on the 'Futures Workshop' approach (Jungk and Müllert, 1987) in which participants work in small facilitated groups to consider ideal worlds, the barriers to reaching them and solutions to overcoming such barriers. In this case, ideal worlds were identified as the successful implementation of mitigation measures.

Challenges were identified for mitigation measures relating to six key components of the farming system: feed, animal husbandry and breeding, manure management, land management, nutrient management and energy efficiency (Supplementary Material B). Recent studies have shown that under some scenarios, the application of mitigation targets to agriculture by EU nations produces significant carbon leakage, i.e. reductions in production and emissions in one area leading to increased production and emissions in another (Huang et al., 2011) through curtailed production and an increase in imports (Fellmann et al., 2018). Therefore, discussions with stakeholders in the current study avoided those mitigation measures that could be expected to reduce production, and focussed on those aimed at: i) reducing emissions through increased production efficiency (Hyland et al., 2016a) (e.g. improving animal health and husbandry, avoiding over-use and inappropriate use of artificial fertilisers, reducing overfeeding, improved manure management), ii) improving the environment in which production takes place to maximise carbon sequestration (e.g. hedges and boundary trees to store carbon (Axe et al., 2017)) – these measures can also increase production efficiency, for example by providing shelter for animals, improving sward growing conditions and providing browse material for improved animal diet and health (Gregory, 1995; He et al., 2017; Mueller-Harvey et al., 2017; Pollard, 2006), and iii) adopting alternative production systems which may alter what is produced, but maintain the productive use of land (e.g. agroforestry systems which can potentially increase carbon sequestration and productivity while offering opportunities to diversify farm incomes and improve resilience to climate change (Eory et al., 2015; Nerlich et al., 2013; Rigueiro-Rodríguez et al., 2009)). Framing discussions around these types of measure also helped focus stakeholders on the specific challenges to implementing GHG mitigation measures, rather than on more general issues relating to reducing production. Within the small groups, challenges were identified by each stakeholder, listed and

discussed. Facilitators worked with groups to merge duplicate challenges. Participants were then invited to suggest and discuss solutions to the challenges listed. However, in the current study, the focus was on the challenges themselves. To ensure that inputs were not biased towards more confident speakers (Kitzinger, 1995), those involved in the exercises were invited to write their ideas on sticky notes for subsequent discussion.

After the workshops, the sticky notes written by participants, information shared during group discussions, and interview data were transcribed for analysis. A grounded theory approach (Charmaz, 2014; Glaser and Strauss, 1967) was used to analyse the data; the data were coded into themes which were compared and contrasted along with the original data, in order to draw out underlying categories that could shed more light on the focus of research. Grounded theory approaches seek to get beneath the surface of the dataset; rather than trying to fit data to a pre-defined categorisation, the categories emerge from them (Charmaz, 2014; Glaser and Strauss, 1967). This type of approach was considered particularly relevant given the diversity of challenges to change in different locations and systems reported in previous work on climate change mitigation (Feliciano et al., 2014). The dataset reached saturation (no new themes or issues arising from successively analysed data) (Charmaz, 2014) across the interviews and workshops.

The categories arising from analysis of the stakeholder data were compared with existing literature and theory; specifically, a comparison was made with: i) a recent comprehensive global review of the barriers to and drivers of the implementation of climate-friendly agricultural practices (Wreford et al., 2017), and ii) the Individual-Social-Material (ISM) model (Darnton and Evans, 2013). These two sources were chosen as a focus, as they represent important and recent syntheses of material from this highly diverse and complex research area.

3. Results and discussion

Twenty nine themes were identified within the data relating to challenges to the implementation of GHG mitigation measures in Welsh livestock agriculture (a full description of themes is provided in Supplementary Material C). Analysis yielded four interacting categories of challenge: Practical limitations, Knowledge limitations, Cognitive limitations and Interests. These categories are discussed in the following sections, and illustrated with relevant quotes from the data.

3.1. Practical limitations

A range of Practical limitations were revealed in the challenges identified by participants (Fig. 1). Measures may not be available or may be limited, and there may be costs related to implementation. Comments relating to costs included not only implementation costs, but also the costs of gathering information to tackle Knowledge limitations:

> "Optimising high end concentrates is very complex, needing a lot of knowledge and often outsourced help"

Practical limitations also relate to nature of the farming system, and to external constraints such as regulation, availability of finance, or international trade. Comments highlighted that Practical limitations affect all actors, not just farmers. For example, the limited budgets of knowledge suppliers can hinder the implementation of change and reduce options:

> "One to one knowledge exchange is too expensive but if groups are formed only the already engaged/efficient farmers attend"

3.2. Knowledge limitations

The data revealed a number of sub-categories making up the category of Knowledge limitations (Fig. 2). Lack of knowledge can limit change at every step from not being aware of available measures and their effects, to not having the skills to choose and implement a measure. Knowledge limitations create risk and uncertainty in relation to the theoretical impacts of a measure, its likely impact on a given system, and how this might change over time (including, for example changes in the financial situation of the farm, the effect of changing climatic conditions on the measure, or potential changes in external factors such as policy). Uncertainty about actual impacts might affect persistence with a new measure if improvements are not measured.

3.3. Interests

Interests (what motivates farmers and other stakeholders and what they value) and perceptions were often explicitly referred to in the data (Fig. 3). A wide range of farmers' interests and motivations were highlighted. These interests interact with the farmers' view of the system (including the nature of their stake in it) and their view of themselves and other actors (who have their own interests and perceptions which shape the system and affect change in different ways). Other actors can affect the choices of farmers directly, or via the information they provide to farmers (Quality of information, Fig. 2). If the interests of specific groups are overlooked or misinterpreted, there may be negative consequences:

> "New agri-environment schemes that do not reward management of current hedgerows etc., and recognise that the farmers signed up to previous schemes to add them, can provide an incentive to remove hedgerows, then join a scheme to be rewarded for putting them back"

Those attempting to implement change must also be aware of historical context and its effect on interests. For example, top-down change can evoke historical events that create hostility and mistrust:

> "Afforestation can be emotive – in the past, communities [were] lost to reservoirs and tree planting. This has to be understood"

3.4. Cognitive limitations

In contrast to issues relating to the availability and receipt of information, which are the focus of the category of Knowledge limitations, the term *cognition* is applied here to refer to the mental processes involved in *using* received information. The category of Cognitive limitations therefore reflects responses relating to constraints and pressures on the thinking processes of stakeholders (Fig. 4). Systemic complexity resulting from farm-scale processes, change in the context in which the farming system operates, and the existence of a range of interests and priorities (those of farmers and of others, like policymakers) means that management requires time, effort and skills in effective thinking (e.g. project management skills). Stakeholders faced with such challenges may develop coping strategies – traditional approaches or habits that enable some aspects of the system to be managed with little new thought, freeing up mental space – however, these may become obsolete or counter-productive if they remain unchanged over time. The category of Cognitive limitations reveals how the same types of factor affecting changes in behaviour (Interests, Practical, Knowledge and Cognitive limitations) also affect how stakeholders are able to think about systems. For example, farmers (and other stakeholders) may have little motivation to think about mitigation measures that lie beyond immediate concerns. Addressing Cognitive limitations therefore requires tackling another level of the four categories of challenge, as well as instilling the Interest to do so. Tackling Cognitive limitations based on a lack of skills, for example, would not entail training to implement a particular practical option, but would focus on providing training on project management or conceptual thinking. Some participants made direct reference to Cognitive limitations:

> "Constantly improving all different aspects of production, weighing

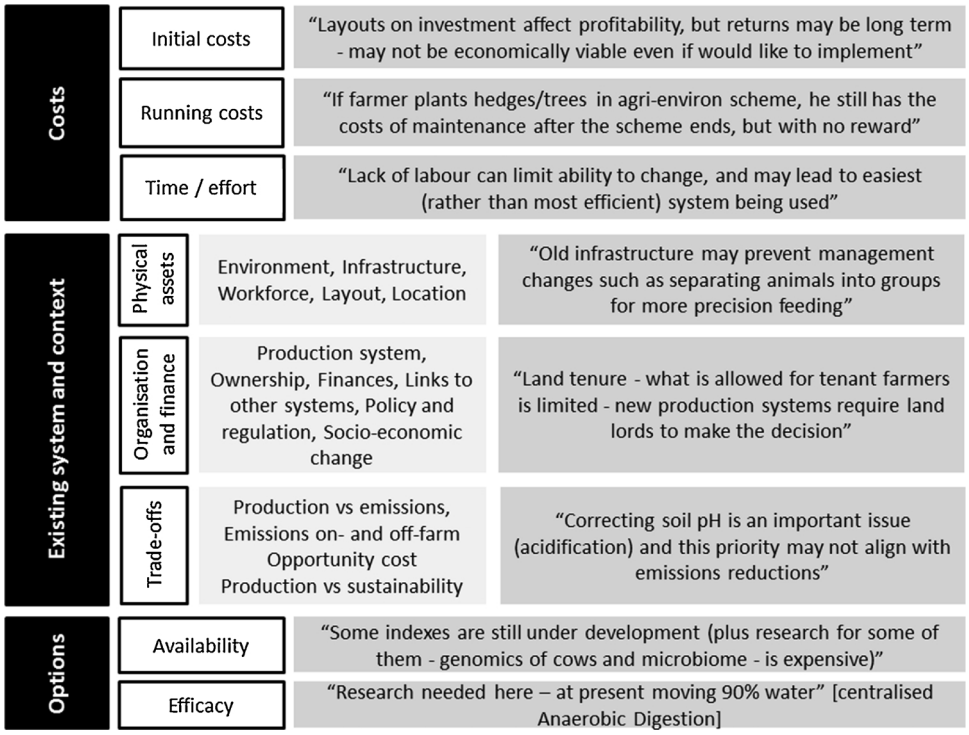
Costs
Initial costs
"Layouts on investment affect profitability, but returns may be long term - may not be economically viable even if would like to implement"
Running costs
"If farmer plants hedges/trees in agri-environ scheme, he still has the costs of maintenance after the scheme ends, but with no reward"
Time / effort
"Lack of labour can limit ability to change, and may lead to easiest (rather than most efficient) system being used"
Existing system and context
Physical assets
Environment, Infrastructure, Workforce, Layout, Location
"Old infrastructure may prevent management changes such as separating animals into groups for more precision feeding"
Organisation and finance
Production system, Ownership, Finances, Links to other systems, Policy and regulation, Socio-economic change
"Land tenure - what is allowed for tenant farmers is limited - new production systems require land lords to make the decision"
Trade-offs
Production vs emissions, Emissions on- and off-farm Opportunity cost Production vs sustainability
"Correcting soil pH is an important issue (acidification) and this priority may not align with emissions reductions"
Options
Availability
"Some indexes are still under development (plus research for some of them - genomics of cows and microbiome - is expensive)"
Efficacy
"Research needed here – at present moving 90% water" [centralised Anaerobic Digestion]

Fig. 1. Practical limitations to change and its sub-categories. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

up alternatives etc. is mentally hard day after day over the long term"

These limitations are likely to affect the efficacy of stakeholder choices:

"Dairy farmers are often at the limit of what they can afford to do, just to survive - this pressure can prevent an integrated approach to land management that takes into account interactions, long term change etc."

When Cognitive limitations exist, new knowledge, opportunities or demands may be ineffective in producing change, because stakeholders will not be able to process new information and/or evaluate its full

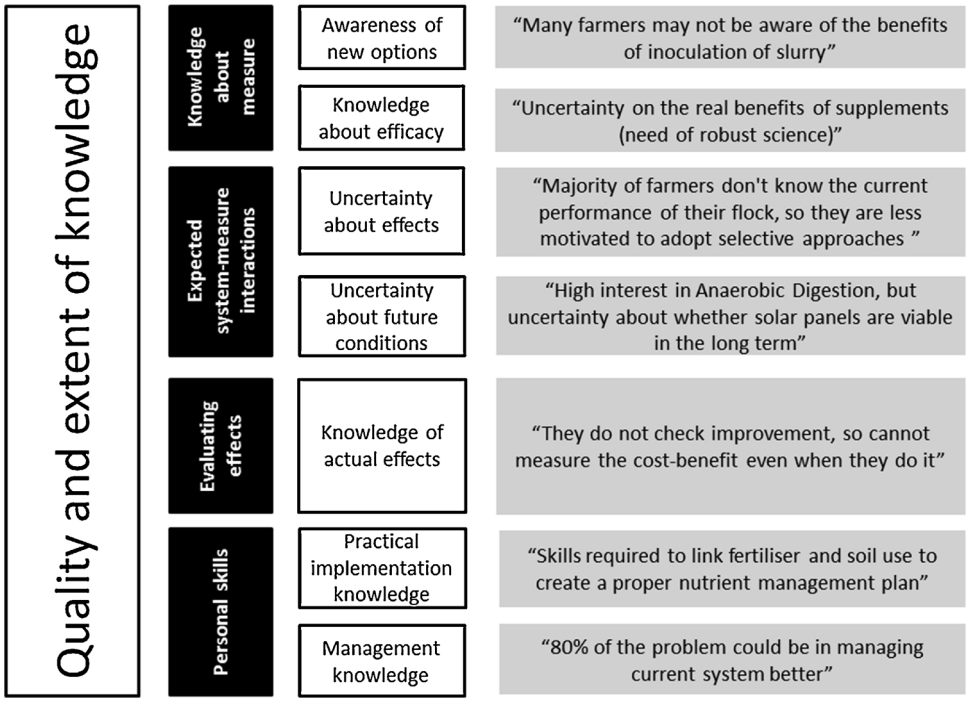
Quality and extent of knowledge
Knowledge about measure
Awareness of new options
"Many farmers may not be aware of the benefits of inoculation of slurry"
Knowledge about efficacy
"Uncertainty on the real benefits of supplements (need of robust science)"
Expected system-measure interactions
Uncertainty about effects
"Majority of farmers don't know the current performance of their flock, so they are less motivated to adopt selective approaches "
Uncertainty about future conditions
"High interest in Anaerobic Digestion, but uncertainty about whether solar panels are viable in the long term"
Evaluating effects
Knowledge of actual effects
"They do not check improvement, so cannot measure the cost-benefit even when they do it"
Personal skills
Practical implementation knowledge
"Skills required to link fertiliser and soil use to create a proper nutrient management plan"
Management knowledge
"80% of the problem could be in managing current system better"

Fig. 2. Knowledge limitations category and sub-categories. Grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right. Knowledge limitations within any sub-category can relate to either the range or the quality of knowledge held by stakeholders.

Farmers' interests
Level of interest
Stake in system, Other occupations
"Increased amounts of land being rented as farmers get older and reduce land managed - no motive for tenants to make any investment in the land "
Nature of interests
Economic, Family, Environment, Social standing
"Need to consider the drivers for farmers - their family and their need to make a living - need to do what is economically best"
Farmers' perceptions
Of system
"Manure not valued as a resource and nutrient levels not known "
Of self
"Farmers feel that production is their purpose - so if you take this away from them, you are taking away their purpose"
Of others
"Deep suspicion about government targets and the language used in policy communication"
Interests and perceptions of others
Media
"Negative views in press - farmers begin to view themselves as sufferers/victims who are treated poorly, and this can reduce their capacity for change"
Social
"Risk for farmers, for example comments from local community if they move away from traditional approaches "
Suppliers
"Might not meet the goals of other industry stakeholders who could then hinder the application of these strategies"
Customers
"Consumers seem to favour welfare/environment, but this is not reflected in rewards for farmers"
Policy
"Regulations on hedge management - do biodiversity and GHG emissions priorities align, or are there conflicts?"

Fig. 3. Interests category and sub-categories. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right.

implications.

3.5. Conceptual framework

Putting together the categories described, the Interests of farmers and other stakeholders interact with Practical and Knowledge related limitations to change, and with the context in which change occurs (Fig. 5). Challenges can be perceived as lying on a continuum from being wholly based on Practical and/or Knowledge limitations to being wholly based on Interests not aligned with implementation. Cognitive limitations affect the ability to understand one's own interests fully, and to recognise limitations, as well as the ability to subsequently reflect on

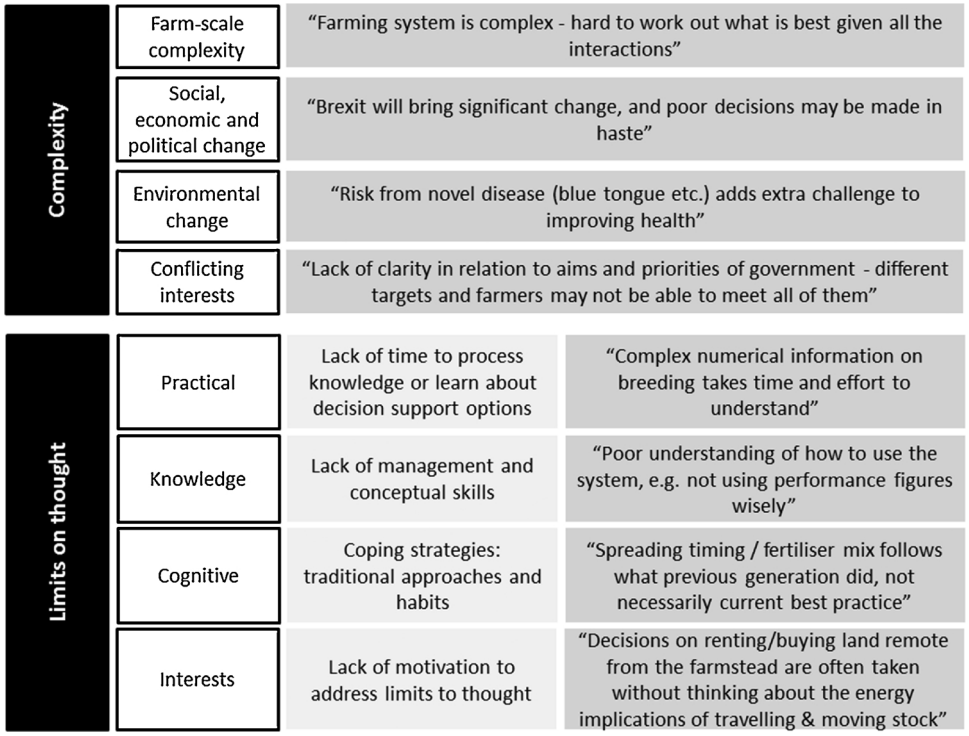
Complexity
Farm-scale complexity
"Farming system is complex - hard to work out what is best given all the interactions"
Social, economic and political change
"Brexit will bring significant change, and poor decisions may be made in haste"
Environmental change
"Risk from novel disease (blue tongue etc.) adds extra challenge to improving health"
Conflicting interests
"Lack of clarity in relation to aims and priorities of government - different targets and farmers may not be able to meet all of them"
Limits on thought
Practical
Lack of time to process knowledge or learn about decision support options
"Complex numerical information on breeding takes time and effort to understand"
Knowledge
Lack of management and conceptual skills
"Poor understanding of how to use the system, e.g. not using performance figures wisely"
Cognitive
Coping strategies: traditional approaches and habits
"Spreading timing / fertiliser mix follows what previous generation did, not necessarily current best practice"
Interests
Lack of motivation to address limits to thought
"Decisions on renting/buying land remote from the farmstead are often taken without thinking about the energy implications of travelling & moving stock"

Fig. 4. Factors creating conditions under which the Cognitive limitations of stakeholders may be reached or exceeded. Dark grey boxes show examples of quotes from stakeholders within each sub-category, and the nesting of sub-categories is shown from left to right.

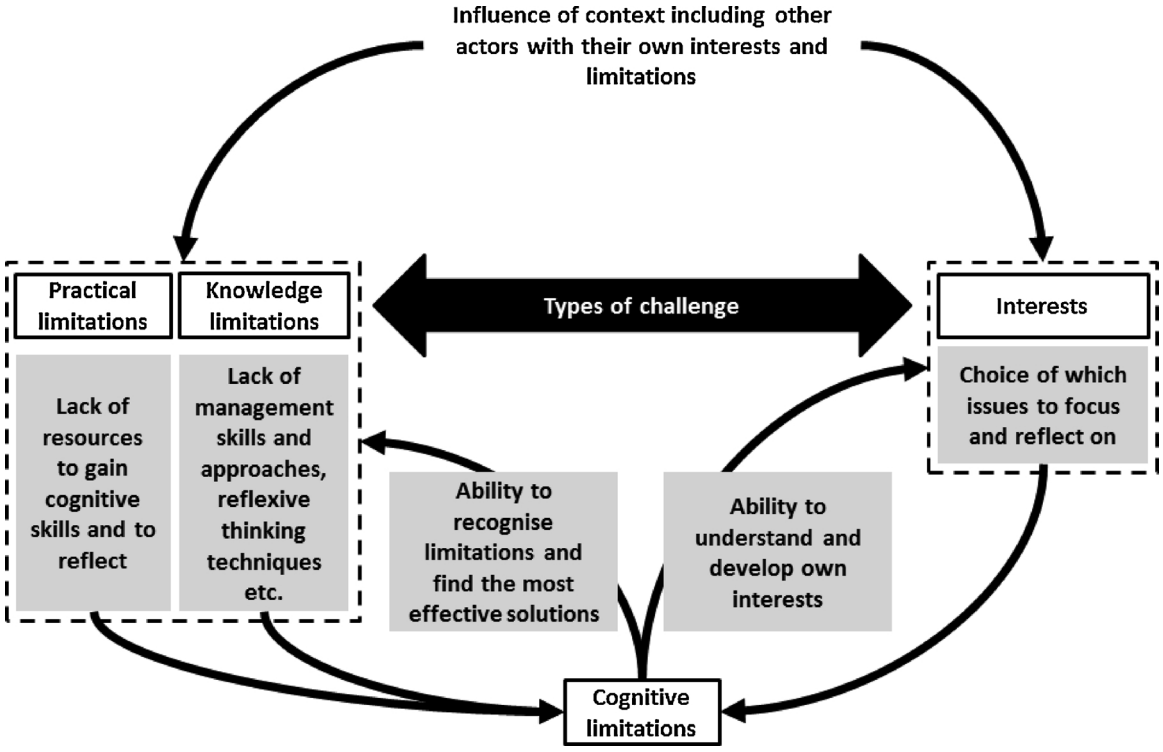
Influence of context including other actors with their own interests and limitations
Practical limitations
Knowledge limitations
Types of challenge
Interests
Lack of resources to gain cognitive skills and to reflect
Lack of management skills and approaches, reflexive thinking techniques etc.
Ability to recognise limitations and find the most effective solutions
Ability to understand and develop own interests
Choice of which issues to focus and reflect on
Cognitive limitations

Fig. 5. Interaction of categories of challenge to the implementation of GHG mitigation measures in Welsh livestock agriculture. White boxes = challenge categories; grey boxes = specific aspects of the categories relating to Cognitive limitations; thin arrows = direction of interactions. Specific challenges to change lie on a continuum (large black arrow) between Practical and/or Knowledge limitations and the Interests of those involved.

both limitations and interests and act accordingly. Given that understanding a problem and applying management and thinking skills to solve it must underpin action, Cognitive limitations bound subsequent processes of realised change. The whole process is influenced by its context, including other actors with their own limitations and interests, who may affect the way that the focus stakeholder perceives their interests, understands their limitations, and chooses options for change.

3.6. Comparison with applied literature

Consistent with previous findings of heterogeneity in the interests, motivations and perspectives of Welsh livestock farmers (Morris et al., 2017; Wynne-Jones, 2013) the current study revealed a complex mix of inter-related challenges to the implementation of GHG mitigation measures, reinforcing the view that a simple economic (profit maximising) model of the actions of the farming community in Wales is not sufficient to understand challenges and support positive change. A comparison between the themes (the least abstracted level of analysis) arising from the current study, and those derived from a global review of factors affecting the implementation of climate-friendly agricultural practices (Wreford et al., 2017) showed subtle differences between the studies, with some of the issues tackled at different levels (Supplementary Material D). However, despite the unique aspects of the Welsh livestock sector (Morris et al., 2017; Wynne-Jones, 2013) the whole range of barriers and drivers relevant to climate change mitigation in the global context (Wreford et al., 2017) was identified in the current study. Although this discussion does not break down current findings by sector, of the 29 themes identified, 24 were derived from both the dairy and the sheep and beef system workshops and interviews, indicating that there were no major sectoral differences in the range of challenge themes (although individual challenges and the relative importance of themes differed by sector). These findings, supported by a similar high degree of overlap with those of Feliciano et al. (2014), suggest that despite regional and local heterogeneity in the specific challenges facing farmers, diverse regions and systems face similar *types* of challenge.

Combining the categories affecting change into a conceptual framework (Fig. 5) illustrates how the problem-centred categorisation cross-cuts the individual-centred approach of recent studies focussed on identifying segments or typologies of farmers to guide improved interventions, such as Hyland et al. (2016b) and Morris et al. (2017). It aligns more with problem-centred conceptual frameworks such as Feliciano et al. (2014) offering a different perspective of the system in which the interests of different groups interact with external limitations.

3.7. Comparison with behavioural change models

Many elements of the framework derived from stakeholder data (Fig. 5) can be found in behavioural change theory. The category 'Interests' is most relevant to theoretical approaches to understanding the factors underpinning motivations and behaviours. However, given the purpose here of gaining an overview of types of challenge, the data do not facilitate the investigation of such theoretical underpinnings (e.g. the development and influence of underlying values and beliefs) but instead focuses on the range of expressed motivations and perceptions and their interaction with other challenge categories. A useful subject of comparison in this respect is the Individual Social Material (ISM) tool developed for Scottish government, which synthesises a range of theoretical approaches into a single model for addressing practical issues relating to climate change adaptation and mitigation (Darnton and Evans, 2013). The division in the ISM tool of behavioural influences into individual, social and material factors is supported in the case of mitigation challenges in Welsh livestock agriculture, by the emergence of categories relating to Interests (individual and social factors), and Practical and Knowledge limitations (material factors). Here, the use of a grounded theory approach also enabled factors and perspectives which might be missed by fitting data to a pre-defined framework, to

Table 2
Comparison of ISM factors and Cognitive limitations. Bold type indicates where cognitive aspects are considered explicitly within ISM.

ISM factor	Description	Framing within the Cognitive limitations category	Role in relation to Cognitive limitations category
Agency	The confidence to undertake a different activity	The confidence to undertake and then rely on a thought process dealing with a complex system – distinct from the confidence to undertake actions	Determinant of level and nature of Cognitive limitation in given cases
Skills	The ability to undertake particular activities	The skills to make decisions about complex systems under conditions of Cognitive limitation – strategies for developing and applying effective mental short-cuts	Determinant of level and nature of Cognitive limitation in given cases
Time and Scheduling	Allocation of time to competing tasks	Allocation of time to thinking about different competing problems (which are prioritised, which considered in-depth, the extent to which short-cuts are applied)	Available time is an external element, prioritising the use of time an internal choice. Lack of time is another determinant of the level and nature of Cognitive limitations in given cases
Costs and Benefits	How people make choices, including **cognitive bias** (mental short-cuts, e.g. discounting, framing, loss aversion, mental accounting)	Cognitive biases are framed as strategies to facilitate choice-making under Cognitive limitations – habits of thought that make decisions easier to make	Strategies for dealing with / symptoms of Cognitive limitations
Habit	Automatic, repeated actions that may be supported by the specific context	Habits reduce the apparent complexity of the system being weighed up, simplifying choices	Strategies for dealing with / symptoms of Cognitive limitations

emerge (Glaser and Strauss, 1967). The categories revealed make two departures from ISM, integrating elements from other areas of research and adding some novel perspectives.

The first difference relates to the category of Cognitive limitations. Cognitive factors are recognised in several ways in the literature. Psychological studies of farmer decision making focus on the cognitive biases that influence deliberative choices. Mankad (2016) describe how cognitive bias affects rational choices, in the form of mental short-cuts that draw on our beliefs and perceptions to simplify large amounts of complex, potentially incomplete incoming information – in relation to farming, this results in individualised logical frameworks and informally developed internal rules. The ISM framework (Darnton and Evans, 2013) considers specific types of cognitive bias, such as discounting, framing, loss aversion and mental accounting. Existing cognitive beliefs can create cognitive dissonance when we are exposed to new evidence that conflicts with established approaches (Mankad, 2016).

Behavioural models such as the Theory of Planned Behaviour (Ajzen, 1991) separate intention from action, extending interventions to change behaviour from the level of changing actions to that of changing intentions. Cognitive bias, as described by Mankad (2016), fits into such models as a factor affecting intention; trying to alter specific cognitive biases is revealed as a more long-term strategy for achieving change, than altering actions without changing intentions, which may lead to only transitory change (Noguera-Méndez et al., 2016). This position is consistent with the siting of cognitive biases within the 'Individual' category of the ISM model (Darnton and Evans, 2013) and the treatment of them as imperfections to be tackled.

In social psychology, cognitive processes have long been recognised in relation to decision making in general; Jager et al.'s (2000) 'Consumat' consumer choice model focuses on the interaction of uncertainty and the effectiveness of current actions in meeting needs. The model predicts that, when needs are better satisfied, and uncertainty low, actors repeat previous behaviours, moving towards imitation of others as their uncertainty increases. When there is low need satisfaction, actors use deliberative reasoning (weighing up different options) to identify better courses of action under low levels of uncertainty, moving towards comparing their actions with those of others as their uncertainty grows (social comparison). Several elements highlighted within the category of Cognitive limitations described here, indicate the applicability of this model to challenges to change in livestock agriculture – these include the role of habits, tradition and the influence of social factors (e.g. views of family, community and other farmers) as well as the importance of uncertainty on choices. Insights from the Consumat model have been applied in the field of vulnerability assessment, with the use of multi-agent based models allowing the social context and individual attributes of actors to be incorporated into predictions about likely vulnerability to change (Acosta-Michlik and Rounsevell, 2005; Acosta-Michlik et al., 2014). However, these studies often focus on predicting behaviour and recommending adaptation measures based on assessments of limitations (including cognition) rather than on tackling the causes of cognitive limitation.

Here, the concept of Cognitive limitations indicates the importance of cognitive processing in relation to the implementation of climate change mitigation measures in Welsh livestock systems. It encompasses the effects of cognition both at the level considered by Jager et al. (2000) in the continuum between more reasoned choices (deliberation or social comparison) and automatic choices (repetition or imitation) and at the level of cognitive biases arising within reasoned choices. Changing intentions is costly in terms of time (Noguera-Méndez et al., 2016) and could be viewed as a transaction cost in relation to the implementation of change; addressing Cognitive limitations is a mechanism for reducing this cost by facilitating more effective thought processes, also allowing wider and more complex factors to be considered. This re-framing and clarification of the role of cognitive factors can be shown by considering which ISM factors relate to the category of Cognitive limitations, and how this goes beyond the explicit role of cognitive bias within the ISM factor 'Costs and Benefits' (Table 2). The category of Cognitive limitations separates the issue of how to align attempts to influence decisions with existing cognitive biases, from the issue of how to best hone cognitive skills, including becoming aware of and developing more effective mental short-cuts.

Although cognitive barriers to change have been recognised in some studies of climate friendly farming, Wreford et al. (2017) judge them as relatively unimportant in relation to the implementation of climate friendly agricultural practices globally. One reason may be that the authors use a narrower definition of cognitive limits than that used here and in the social psychology literature; for example, they consider the competing pressures facing farmers, and the need for robust management strategies to deal with climate change risks and uncertainties, but do not relate this issue to cognition. The findings presented here suggest that the importance of cognitive processes needs to be more fully and widely recognised in relation to implementing climate change mitigation measures in agriculture, and specifically that Cognitive limitations can be treated as a focus for intervention to improve uptake, rather than as a fixed problem to be worked around.

The second way that current findings depart from behavioural change approaches is that the category of Interests encompasses recognition of the interests of the supply chain and customers as challenges to implementing change, consistent with recent political

economy studies considering climate smart agriculture. Newell and Taylor (2018) argue that, at the global level, agro-business and fund-seeking institutions act to direct the climate smart agriculture agenda towards solutions consolidating current global food production systems within a neo-liberal market framework. The findings presented here show the relevance of such issues to on-the-ground changes in the Welsh livestock agricultural sector. Such challenges were exemplified by the role of suppliers as information providers, the use of farm data by suppliers and customers to direct farmers' choices (e.g. companies developing breeding indexes and processors), the availability of mitigation solutions, and the direct effect of policy and global context as external pressures. Power relationships and their consequences can often be left unchallenged under pragmatic approaches to change, which seek consensus rather than revealing and discussing conflicts (Johansson and Lindhult, 2008). Research projects engaging stakeholders often take such pragmatic approaches, focussing on exploitative (making better use of current systems) rather than exploratory solutions, and may not support the transformative approaches that could be necessary to tackle the challenges of climate change (Martin et al., 2013).

Behavioural change models recognise the importance of understanding that other actors influence the group on which change is focussed, and that the behaviours of such actors are affected by the same factors as those affecting farmers' choices (Mankad, 2016). Using such theories to implement change relies on those involved reflecting on their actions (Morris et al., 2012). However, the problems associated with determining what changes are implemented, how and why they were chosen lies beyond the scope of behavioural change approaches, which focus on facilitating pre-determined change. Despite such issues being recognised in the applied literature on the implementation of climate-friendly changes (Wreford et al., 2017) they may not always be considered by policymakers seeking the practical support offered by behavioural change tools. The findings here highlight the importance of acting with awareness of the ethical issues relating to the use of behavioural change approaches (Clavien, 2018). As well as having social justice implications, ignoring or marginalising the consideration of critical elements may hinder implementation efficacy. An example is the role of historical context in shaping stakeholder responses to engagement (Ison et al., 2007). Here, experiences of past afforestation and the flooding of valleys were associated with suspicion of government and reluctance to embrace new production systems or accept payments in exchange for reducing current agricultural production.

The current study asked stakeholders to consider broadly the challenges to implementing GHG mitigation measures, to gain an overview of the scope and types of challenge to change. As a result, there were limits to the depth of investigation of specific challenges. More detailed investigation is needed to better understand specific components of the challenge categories, to consider how challenges differ for specific types of individual, in relation to specific concrete mitigation measures, and in relation to more local geographic and systemic contexts. This would include incorporating work on the impacts of different perceptions of climate change amongst farmers (Barnes and Toma, 2012; Hyland et al., 2016b) and other stakeholders, which were not put forward by stakeholders in the current study as challenges to change. This omission is likely to reflect the fact that those who reject the idea of climate change would be unlikely to engage in research focussed on implementing GHG emissions reduction measures. In principle, differences in perception would fit within the 'Interests' category of challenges as defined here, affecting the motivation for action, but may also reflect Knowledge limitations associated with understanding the concept of, and evidence for, climate change. The scope of the current work could also be extended through research to understand the relevance of the conceptual model developed to other farming sectors (e.g. cereal, horticulture or mixed farming) or to the related challenge of implementing climate change adaptation measures. While understanding challenges to change is an important first step in developing effective policy, further work is needed to consider i) how and to what extent different approaches to implementing change tackle the categories of challenge identified, and ii) what the potential impacts of different strategies are likely to be.

4. Conclusions

The findings presented indicate that the implementation of GHG mitigation measures in livestock agriculture will require the application of trans-disciplinary understanding to enable specific challenges across the four challenge categories to be tackled effectively. In particular, efforts to implement change should recognise the underlying role of Cognitive limitations as a challenge to change and the need for critical examination of how and by whom change is determined, implemented and governed. The conceptual framework developed provides a tool to support policymakers in identifying challenges to the implementation of GHG mitigation measures in livestock agriculture, and subsequently in designing policies tailored to effectively tackle them.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2018.11.013.

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